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GEOLOGY OF THE WATERFORD RIVER BASIN
St. John's, Newfoundland

by

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Urban Hydrology of the
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Technical Report T-2

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Map 1: Geology of the Waterford River Basin, by A.F. King, 1984. (in pocket)

ABSTRACT

All rocks within the Waterford River Basin are of latest Precambrian age (circa 700-600 Ma). Bimodal volcanic rocks of the Harbour Main Group occur west of the watershed and are overlain within the basin by three contrasting clastic sedimentary assemblages, which, in order of decreasing age, are the Conception, St. John's, and Signal Hill Groups. These groups are subdivided into nine formations, which have been traced throughout the area.

The rocks provide evidence of two phases of deformation. The first phase is assumed to relate to the Precambrian Avalonian Orogeny and the second to a major Siluro-Devonian (circa 395 Ma) disturbance - the Acadian Orogeny.

Hydrologically, the most significant features influencing groundwater movement in the basin are major plunging folds and fracture zones in low porosity rocks of the Drook Formation which generally slope toward the Waterford and South Brook Rivers. Tuffaceous siltstones (Mistaken Point Formation) and black shales (St. John's Group) conformably overlie the Drook Formation in the Mount Pearl area; both rock units show fractures and slaty cleavage which provide conduits for groundwater movement. Secondary growths of pyrite and pyrolusite are commonly altered to iron and manganese precipitates along fractures, particularly in the cherts of the Drook Formation and the thinlybedded sandstones of the Renews Head Formation, and are known to have an adverse effect on water quality.

INTRODUCTION

Location

This survey was conducted as part of the joint Waterford River Basin Urban Hydrology Study currently being undertaken by the Canada and Newfoundland Departments of Environment. The Waterford River Basin map area is centered around the rapidly expanding town of Mount Pearl, southwest of St. John's Harbour. It is bounded by the Kenmount Hill in the north, the South Side Hills in the east and the Paradise, Bremigens and Cochrane Pond hills to the west.

The Waterford River has a generally eastward flow and extends from Bremigens Pond to St. John's Harbour, a distance of 14 km. The main tributary is South Brook, which has its source about 2 km south of Bremigens Pond.

The western part of the city of St. John's and the town of Mount Pearl show both commercial and residential development along the Waterford River valley while farmland borders South Brook.

Regional Geological Setting

The Appalachian Orogen in Newfoundland has been divided into four main tectonostratigraphic zones (Figure 1, index map), each displaying a distinctive pre-Silurian evolutionary history (Williams, 1976, 1978; Williams and Hatcher, 1983).

The Avalon Zone lies to the east of the Dover-Hermitage Fault (Figure 1) and consists mainly of thick sequences of late Precambrian volcanic and sedimentary rocks, locally overlain by Paleozoic sediments with body and trace fossils characteristic of the Atlantic realm. Similar rocks occur in Nova Scotia (Keppie and Schenk, in King, 1982), New Brunswick (Ruitenberg et al., 1973) and throughout the Appalachian Orogen in the southeastern United States (Rast, 1980; Skehan and Murray, 1980; Hatcher et al., 1980). The Avalon Zone continues in

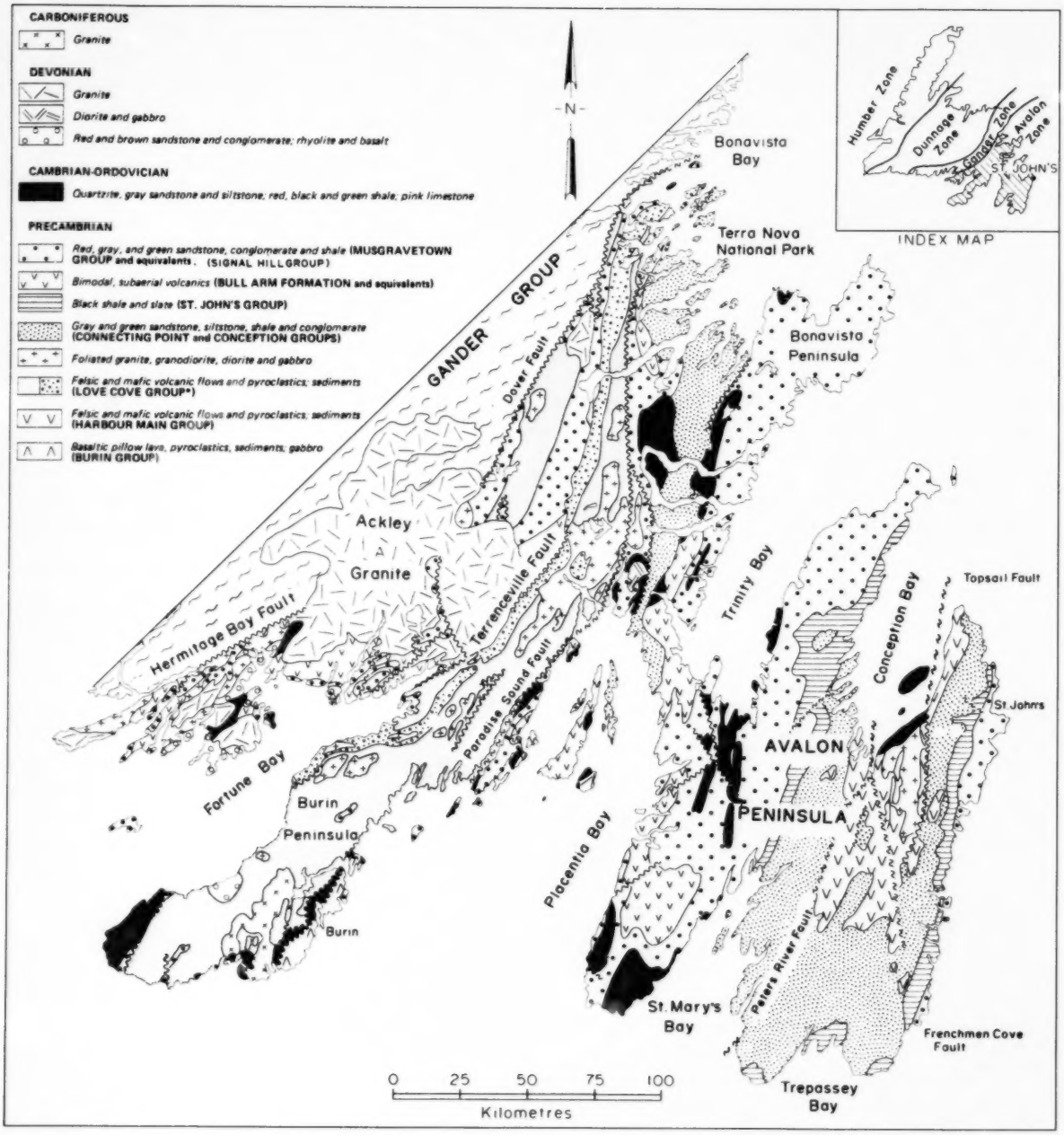

Figure 1: Geological map of the Avalon Zone in Newfoundland (King and O'Brien, in press). Index map shows major tectonostratigraphic zones of the Newfoundland Appalachians.

the offshore Grand Banks of Newfoundland for some 250 km to the present continental margin (Lilly, 1966; Haworth and Lefort, 1979). Similar rocks occur in the southern part of the British Caledonides, in the Hercynides of France and Iberia, and in the northern and eastern margin of the west African shield (e.g. Rast, 1980; O'Brien et al., 1983; King and O'Brien, in press).

The Avalon Peninsula (Figures 1 and 2) is geologically part of the Avalon Zone. Relatively unmetamorphosed late Precambrian volcanic, turbiditic and molasse-like rocks, locally overlain by Cambrian and Ordovician marine shelf sediments, define major elongate structural domes and basins. The Precambrian rocks are intruded by granite that is nonconformably overlain by Cambrian shales. The rocks were first deformed in the late Precambrian and, subsequently, regionally deformed and metamorphosed during the mid-Paleozoic Acadian orogeny.

Previous Geological Work

The first geological report and map of Newfoundland by J.B. Jukes (1843) provided a description of the rocks of coastal Avalon Peninsula, including a brief account of the main rock types around St. John's. This was followed by the reconnaissance studies of A. Murray and J.P. Howley who, in 1881, published a map of the entire Avalon Peninsula showing the distribution of formations. They depicted a core of "Laurentian Gneiss" in the eastern part flanked by a concentric arrangement of "Huronian" slates, sandstones and conglomerates. Their auriferous slates and sands (unit c) correspond to the present Conception Group, their Aspidella slates (unit d) to the Fermeuse Formation of the St. John's Group, and their overlying Signal Hill grey sandstone, red sandstone and conglomerate (units e, f, g) to the Gibbett Hill, Quidi Vidi, Cuckold and Blackhead Formations of the present Signal Hill Group.

Geological studies of the St. John's Peninsula include general mapping by Rose (1952), Brueckner (1969, 1979), King (1972, 1974, 1977, 1980, 1982) and Hsu (1975). The surficial geology and geomorphology of the Avalon Peninsula have been described by Henderson (1972), Brueckner (1979) and Heringa (1981). The surficial geology of the Waterford River basin has been investigated by Batterson (1984).

Present Study

The present survey was undertaken during June 1984, under contract with the Water Resources Division of the Newfoundland Department of Environment, to determine the late Precambrian lithofacies and tectonic elements as a data base for hydrogeological studies. It represents the first systematic detailed mapping and division of the Conception, St. John's and Signal Hill Groups in the Waterford River basin since these groups were subdivided on a regional scale by Williams and King (1979). As a result of this study, the rocks have been subdivided into formations, their distribution and lithofacies described, and the local structure outlined. Of particular interest is the evidence for a first phase of deformation (the Avalonian Orogeny) followed by a second major disturbance (the Acadian Orogeny).

Most of the roadsides and tracks in the low-lying part of the map area were checked for outcrops. Hills on the perimeter of the basin were investigated in some detail and traverses were run from roads, and along rivers, trails and transmission lines. Coloured and black and white aerial photographs were

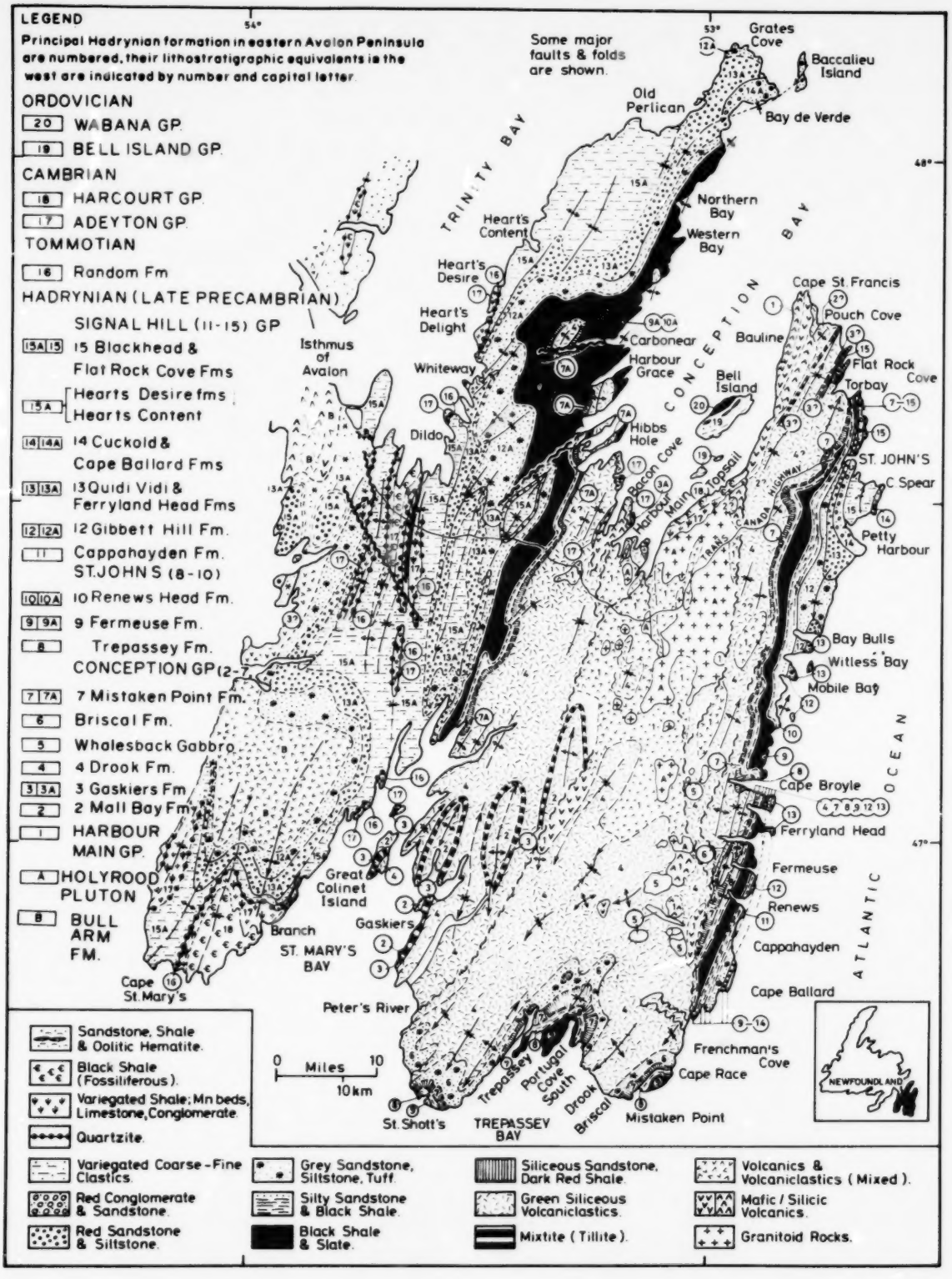

Figure 2: Geology of the Avalon Peninsula (modified after King, 1980, 1982).

used to trace tectonic structures and lithofacies in the field; aerial photographs taken in the mid-1940's were particularly useful in determining structural trends in former areas of bedrock that are now industrial or housing estates. Samples were collected across the field area for subsequent analyses and petrographic study. Dominant rock types constituting both subcrop and till were also noted. In total, 200 point descriptions were completed. Data were plotted on Department of Forestry and Agriculture maps, Numbers 0255, 0256, at a scale of 1:12,500.

Physiography and Glaciation

Bedrock geology largely controls the physiography of the basin. Weather resistant beds of arkosic sandstone and conglomerate of the Signal Hill Group form the north-northeasterly trending South Side Hills. Hard siliceous beds of the Drook Formation form prominent hills and rocky ridges in the western and northern parts of the basin. On the other hand, less resistant tuffaceous siltstones of the Mistaken Point Formation and shales of the St. John's Group form the low-lying central interior.

About 90 percent of the field area is covered by a veneer of till. The surficial deposits were described by Batterson (1984). It was found during the present study that there is a close correlation between type of bedrock and dominant clast type in till, indicating that the till veneer is of generally local origin and did not travel far. Gravel ridges that are conspicuous on aerial photographs in the western part of the area trend parallel with bedrock structures.

The orientation of ridges together with glacial striae suggests that a thin topographically controlled ice cover flowed in a curvilinear path across the basin from west to southeast and then northeast via St. John's Harbour. Glacial striae observed on cherts east of Octagon Pond suggest ice movement toward the west-northwest (azimuth 290°), indicating a divide between Octagon Pond and Bremigens Pond.

GENERAL GEOLOGY

General Statement

Waterford River Basin map area consists of late Precambrian clastic sedimentary rocks that are folded into broad anticlinoria and synclinoria. Regional lithological correlations indicate some degree of formational homogeneity (King, 1980, 1982).

Marine and terrestrial, mafic to acidic volcanic rocks of the Harbour Main Group appear to be the oldest exposed rocks in the Avalon Peninsula of Newfoundland and are presumed to be Late Riphean (1000-670 Ma). These rocks are exposed in northwestern Paradise (Map Sheet 0255) but are outside the basin boundary and are, therefore, only briefly described. They are intruded by granitoids of the 620 Ma Holyrood Plutonic Suite.

The volcanic rocks are associated with Vendian (670-590 Ma) turbidites and marine volcaniclastic sedimentary rocks of the Conception Group (Rose, 1952). This group is represented within the periphery of the Waterford River Basin by the Drook and Mistaken Point Formations.

The Conception Group is conformably overlain by a shallowing upward marine sequence of dark grey shale and sandstone of the St. John's Group (Williams and King, 1979). The St. John's Group consists of the Trepassey, Fermeuse and

Renews Head Formations and occurs within the central part of the map area.

A coeval alluvial plain sequence, the Signal Hill Group (Williams and King, 1979), occurs in the South Side Hills and is divided into the Gibbett Hill, Quidi Vidi, Cuckold and Blackhead Formations. Green sandstones of the Gibbett Hill Formation are gradational and conformable with the irregularly bedded Renews Head sandtones of the St. John's Group. There is erosional truncation of Gibbett Hill beds by red sandstones of the Quidi Vidi Formation. Red conglomerates and arkoses of the Cuckold Formation are gradational with underlying rocks of the Quidi Vidi Formation and overlying red sandstones of the Blackhead Formation. The Cuckold and Blackhead Formations outcrop to the east of the Waterford River basin and are briefly described.

Harbour Main Group and Holyrood Plutonic Suite

The **Harbour Main Group** (Rose, 1952) underlies much of central Avalon Peninsula (Figures 1, 2) and is disposed in three lithologically distinct fault blocks (Rose, 1952; McCartney, 1967; Papezik, 1969, 1970; Hughes and Brueckner, 1971).

Volcanic rocks of the eastern block are brought up along the Topsail Fault (Figure 1), which follows the eastern shore of Conception Bay. This block is dominated by pillow lava, aquagene tuffs and associated volcaniclastic sedimentary rocks. Rhyolite domes dated at 585 Ma by U/Pb/zircon (Krogh et al., 1983) intrude the assemblage.

In the Paradise area, approximately 3 to 4 km west of the Waterford River basin, mixed dark green mafic lava and siliceous sedimentary rocks of the eastern block are intensely fractured and have a steep easterly dipping foliation. Small stocks of diabase and gabbro are present about 1 km northwest of Ryalls Pond but their age and relationships to the Harbour Main and Conception Groups are unknown.

The central block to the west of the Topsail Fault includes felsic and mafic flows, pyroclastics and minor volcaniclastics, intruded by 620 Ma (Krogh et al., 1983) high level granite, quartz monzonite and granodiorite of the **Holyrood Plutonic Suite** . The volcanic rocks were intruded during the closing stages of the Avalonian Orogeny; both volcanic and granitoid rocks are overlain by fossiliferous Lower Cambrian shale and limestone.

The western block, exposed west of the Peters River - Holyrood Fault (Figure 1), is characterized by the products of subaerial eruptions, including several belts of well preserved acidic ash-flow tuffs locally intercalated with fluvial and lacustrine volcanogenic sediments and overlain by terrestrial massive and amygdaloidal basalt flows (Nixon and Papezik, 1979).

Much of the eastern volcanic block was formed in a shallow marine environment, in contrast to the typically subaerial depositional environments to the west. The Harbour Main Group, with young dates of 585 Ma, may be partially related in time to the Bull Arm Formation of western Avalon Peninsula. Both volcanic units are mildly alkalic to tholeiitic. On the basis of their chemistry and mineralogy, the mafic flows of the Harbour Main Group are classified as hawaiites and mugearites, metamorphosed under conditions of the prehnite-pumpellyite facies, and show intraplate chemical affinities (Papezik, 1970; Nixon and Papezik, 1979).

Clasts of rhyolite and granite are common pebble types within the Signal Hill Group (Cuckold Formation) in the eastern part of the map area.

Conception Group

The **Conception Group** (Rose, 1952) occurs throughout Avalon Peninsula and is dominated by green to grey siliceous volcaniclastic sedimentary rocks of the Drook Formation, representing widespread marine turbiditic and pelagic sedimentation. The abundance of tuff and other volcanic detritus throughout the entire 3 to 5 km thick sequence suggests sedimentation contemporaneous with volcanism, perhaps, as suggested by Hughes and Brueckner (1971), related in time to Harbour Main Group volcanism.

The distribution of Conception Group rocks within the Avalon Peninsula is shown on the regional maps of Rose (1952), McCartney (1967), Hsu (1975), Williams and King (1979) and King (1980, 1982). Rose (1952) informally divided the Conception Group in the Torbay area into Conception Slate and Torbay Slate (names originally introduced by Walcott, 1899) but did not define their regional boundaries. Brueckner compiled a regional map of Conception Group rocks, based on his own observations and on detailed studies by Memorial University of Newfoundland students (in King et al., 1974). Hsu (1975) subdivided the Conception Group north of Windsor Lake into three informal lithostratigraphic divisions: a lower arkosic sandstone unit, a tilloid, and an upper unit of greywacke, siltstone, shale, chert and minor tuff, which is shown on his map of the St. John's peninsula extending southward from Windsor Lake into the Kenmount Hill - Donovans area.

During the 1974-75 field seasons, Williams and King divided the Conception Group of southeastern Avalon Peninsula into f[illegible] formations, which in ascending order are **Mall Bay, Gaskiers, Drook, Briscal** and **Mistaken Point** (Williams and King, 1979). Studies by King (1980, 1982) have shown that these formations can be traced throughout much of the Avalon Peninsula (Figure 2) and are also important in global stratigraphic correlations (O'Brien et al.,1983; King and O'Brien, in press). A distinctive tillite unit up to 300 m thick (Gaskiers Formation) occurs near the base and tuffaceous siltstones and sandstones with well preserved metazoan fossils (Mistaken Point Formation) occur at the top (Figures 2 and 3); the tillite and metazoan fossils are discussed by Anderson and King (1981) and Anderson and Morris (1982).

Conception Group rocks within the map area are represented mainly by the Drook and Mistaken Point Formations. The latter is part of a long, continuous band extending from Trepassey to Torbay (Figures 2, 3, and 4). Yellowish green to white weathering siliceous silty sandstones and bedded cryptocrystalline cherts of the Drook Formation are well exposed in the western and northern hills of the Waterford River basin. The distinctive green and red rocks of the Mistaken Point Formation are exposed in the low lying area west of Mount Pearl and to the north of the Village Mall.

Drook Formation

The Drook Formation is the thickest and most extensive unit in the map area. The Paddy's Pond and Cochrane Pond Anticlines provide the longest and most complete cross-sections through the Drook Formation on the Avalon Peninsula (Map 1). The

formation has an exposed thickness of about 1000 m in comparison with 1500 m estimated for the same rock unit in its type section. Three main facies of the Drook Formation within the map area are described in ascending order:

(a) Siliceous sandstones and chert facies

Along the axis of the Paddy's Pond Anticline, numerous roadcuts and quarries between Bremigens and Paddy's Ponds indicate that the Drook Formation consists dominantly of parallel-sided, medium- to thick-bedded dark green siliceous silty sandstone alternating with thin-bedded yellowish green tuffaceous siltstone, green chert and minor shale. Locally, the siliceous rocks contain abundant pyrite cubes and show black dendritic growths of pyrolusite along fractures; limonite and manganese stains are also common on fracture surfaces, indicating highly oxidizing conditions.

Common sedimentary structures in this turbiditic sequence include graded bedding, convolute lamination, parallel and small-scale ripple cross-laminations, rip-up clasts, and sole and load marks. The presence of tuffs and cryptocrystalline chert of volcanogenic origin indicates active volcanism during sedimentation.

Possible local correlatives of this cherty facies are the beds in Donovans, Wishingwell Road and Kenmount Hill areas. A ridge of dark green, very dense chert with conchoidal fracture forms the northwestern boundary of the Waterford River basin at Robert Heights, Paradise. Dark green turbiditic sandstones in the core of the Donovans Anticline (exposed at O'Keefe's Quarry north of Brazil Pond) are comparable with those rocks in the quarries south of Bremigens Pond, and are probably at the same stratigraphic level. Dark green chert and grey siliceous sandstone in the tightly folded core of the Wishingwell Road Anticline form the northern boundary of the Waterford River basin near Georges Pond; it reappears in the tightly folded core of Kenmount Hill.

(b) Streaky white and red siliceous sandstone facies

A distinctive unit (<100 m thick) of streaky white and red siliceous sandstone directly overlies the dark green siliceous sandstone and chert facies. This facies can readily be traced from Bremigens Pond, around the Paddy's Pond and Cochrane Pond Anticlines, to the Ruth Avenue Overpass along the Harbour Arterial Road. The sandstones are arkosic, with pink to buff weathering feldspar grains. Streaky wisps of red mudstone and thin lenses consisting of granule size argillite and tuff fragments define a coarse parallel lamination throughout the rock. This unit in interpreted as marine, coarse sheet-sand facies. The presence of red mudstone laminae is a precursor to the red facies of the overlying Mistaken Point Formation. This unit has a relatively higher porosity and a lower density than facies (a).

Similar sandstones above the Drook Formation in the Trepassey map area were assigned to the Briscal Formation by Williams and King (1979). The Briscal Formation is a southward thickening and southward derived clastic wedge varying from less than 100 m north of Aquaforte Harbour to 1200 m before entering the Atlantic Ocean near St. Shott's.

Although distinctive and easily traceable west of Mount Pearl, this thin facies is present but poorly exposed in the northern part of the map area and is impracticable to map

at the formational level. It is therefore regarded as a coarse facies within the upper part of the Drook Formation and a possible correlative of the Briscal Formation of southern Avalon Peninsula.

(c) Tuffaceous siltstone and sandstone facies

The streaky white and red sandstone facies in the map area is directly overlain by a fining upward sequence of graded siliceous sandstones and interbedded siliceous siltstone and tuffs. As bed thickness decreases upward from medium to thin, the ratio of tuff and silt over sand increases upward. The top 10 m of this approximately 50 m thick unit is mainly capped by alternating yellowish green tuff and reddish purple sandy tuffaceous siltstone. The tuff beds are highly siliceous porcellanites; in thin section, devitrified volcanic glass shards are recognizable. Varieties include lapilli, crystal, shard and ash tuffs. Lithic fragments are mainly rhyolitic. Graded bedding, convolute and parallel laminations, and load casts show that the tuffs were waterlain and were reworked by sedimentary processes during and shortly after their deposition.

This easily recognized volcanogenic facies was traced around the plunging folds between Bremigens Pond, the Trans-Canada Highway/Harbour Arterial Road Junction to the Ruth Avenue Overpass (about 1 km east of the TCH). In the northeastern part of the map area, this facies outcrops in the highest exposed beds of the Georges Pond Syncline and reappears on the west flank of the Wishingwell Road Anticline near the Elmcliff Street - Mt. Carson Avenue intersection. It is chosen to define the top of the Drook Formation in the map area. The concentration of tuff beds indicates that it is a chronologic marker as well.

Mistaken Point Formation

The name Mistaken Point Formation was proposed by Williams and King (1979) for the interbedded greenish grey and reddish purple tuffaceous siltstones, shales and sandstones that conformably overlie the Briscal Formation in southern Avalon Peninsula (Figure 2). It has been traced northward from the type locality to Cape Broyle, where it directly overlies the Drook Formation (Figure 3), and from there, through the Mount Pearl - St. John's - Windsor Lake area to Torbay (Figure 4). The formation is approximately 400 m thick throughout the Avalon Peninsula.

The Mistaken Point Formation is about 350 to 450 m thick in Donovans Industrial Park. The distinctive green and reddish purple argillaceous rocks which make up most of the formation are sporadically exposed in the low lying area between Ruth Avenue Extension and the ridge between Brazil and Bremigens Ponds which forms part of the western boundary of the Waterford River basin. Although the argillaceous beds have a massive appearance, finely spaced parallel laminations are recognizable. They can be distinguished from similar looking argillaceous rocks in the Drook Formation by their softness and blocky irregular fractures; these fractures are the primary conduits for groundwater movement as they show iron and manganese staining and make the rock highly susceptible to frost action. Drill hole samples from the argillaceous units within the Mistaken Point Formation are commonly ground to a claylike pug (e.g. Drill Hole B) in contrast with the hard siliceous rock chips from the Drook Formation (e.g. Drill Hole G).

Argillaceous rocks of the Mistaken Point Formation are apparently conformably overlain by the

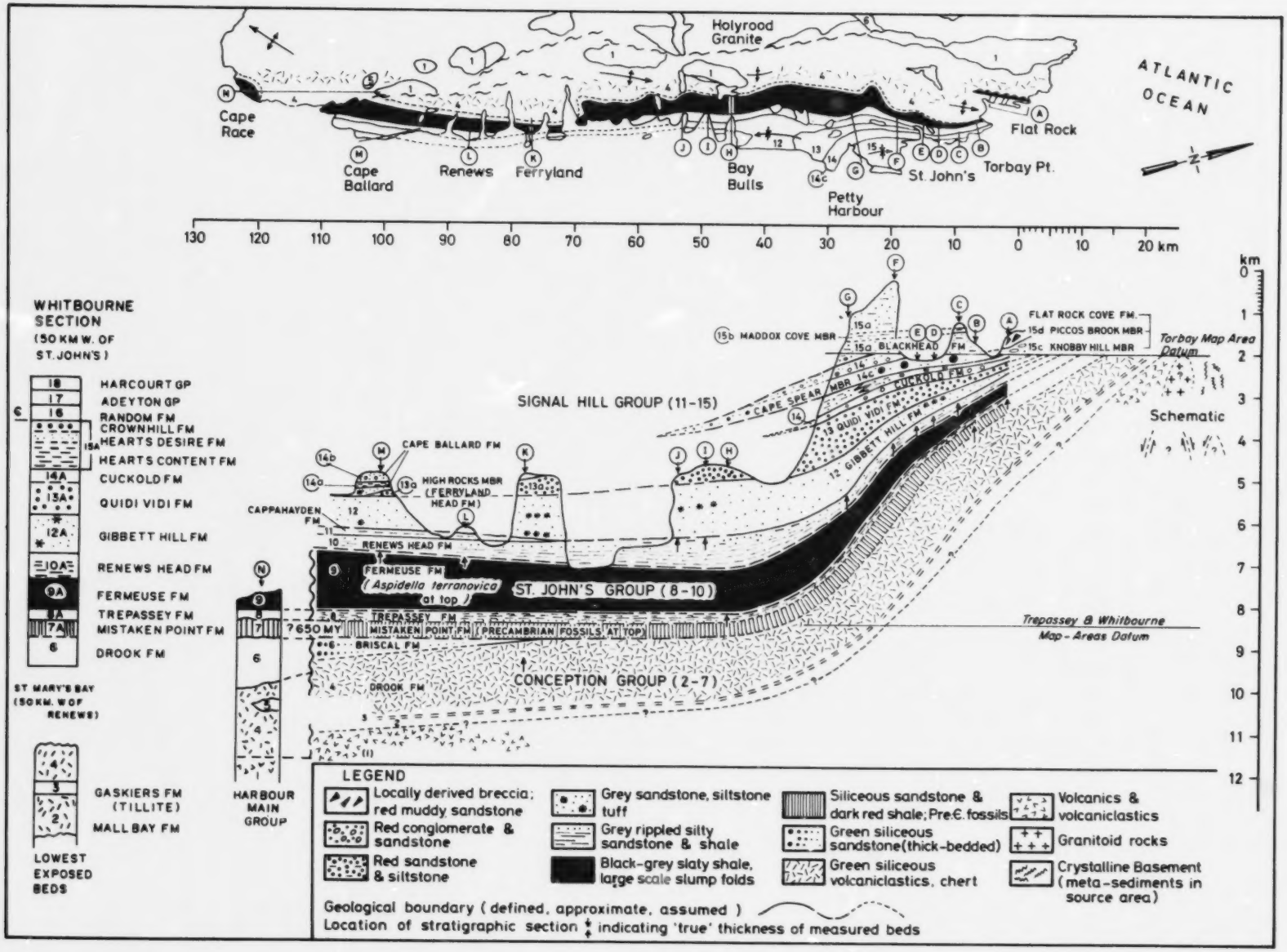

Figure 3: Stratigraphic profile of the Avalon Peninsula (King, 1982).

black shales of the St. John's Group in the northeastern part of Donovans Industrial Park. Although the precise boundary between them is unexposed, it is assumed to extend from the Industrial Park close to Fourth Street (Mount Pearl) and from there, southward close to the Ruby Line - Harbour Arterial Overpass.

In the northeastern part of the Waterford River Basin, intermittent exposures, subcrop and till of red and green argillaceous rocks occur between Blackmarsh Road and Canada Drive; much of this area is assumed to consist of the Mistaken Point Formation. In a large field immediately north of the Canada Drive - Stephenville Street intersection, steeply south to southwest dipping green siltstones and sandstones of the Mistaken Point Formation are conformably underlain by siliceous sandstones and cherts of the Drook Formation. About 200 m north of the Canada Drive - Cowan Avenue intersection, the siltstones of the Mistaken Point Formation terminate against the black shales of the St. John's Group along the axis of a broken, tightly folded syncline.

Late Precambrian metazoan fossils have been found in the Mistaken Point Formation elsewhere on the Avalon Peninsula. None have been found within the map area, perhaps because of the lack of suitable bedding plane surfaces. At its type section on Mistaken Point, the formation is profusely fossiliferous with a variety of frondlike and disclike impressions (Anderson and Misra, 1968; Misra, 1969, 1971; Williams and King, 1979; Anderson, in King, 1982; Anderson and Morris, 1982). The late Precambrian forms occur on bedding plane surfaces and, in all cases, they occur beneath dark, thin, tuff horizons that are less than 1 cm thick. Fossil horizons are most common toward the top of the formation and five or more fossiliferous horizons are easily identified at the type locality.

The profusely fossiliferous Mistaken Point strata define a biostratigraphic zone as well as a lithologic formation. The concentration of thin tuff beds in the formation indicates that it is also a chronologic unit. This easily recognized formation was therefore chosen by Williams and King (1979) to define the top of the Conception Group.

St. John's Group

The Conception Group is conformably overlain by up to 2 km of marine shales and interbedded thin sandstones of the **St. John's Group** (Williams and King, 1979), interpreted by King (1980) as a deltaic to shallow marine sequence which progrades and thickens southward (Figures 3 and 5).

The group consists of three lithic units of formational status, which from bottom to top were defined in 1974-75 as the **Trepassey, Fermeuse,** and **Renews Head Formations** (Williams and King, 1979). The Fermeuse and Renews Head Formations were previously mapped as St. John's slates (Jukes, 1842), Aspidella slates (Murray and Howley, 1881), St. John's Formation (Rose, 1952), and in 1974 were informally termed the Middle Cove and Outer Cove formations,respectively, by Hsu and King.

Throughout the Avalon Peninsula, the Trepassey, Fermeuse and Renews Head Formations constitute a continuous, conformable sequence of grey to black cleaved shales and grey to buff sandstone with gradational contacts. The top of the St. John's Group in the map area is marked by a gradational contact with the Gibbett Hill Formation at the base of the Signal Hill Group.

Trepassey Formation

Light grey tuffaceous siltstones, shales and thin sandstones form the lowermost unit **(Trepassey Formation)** of the St. John's Group and represent a transitional zone into the underlying Mistaken Point Formation with its distinctive green and reddish purple argillaceous units. The Trepassey Formation is approximately 250 m thick throughout southern Avalon Peninsula but thins northward to about 10 m at Middle Cove (Figure 3).

Small sporadic exposures of the Trepassey Formation occur along the Waterford River in the northern part of Donovans Industrial Park. The lower and upper boundaries of the formation approximately coincide with Drill Holes A and F, respectively, suggesting a maximum stratigraphic thickness of 100 m. The lower beds are transitional into the Mistaken Point Formation; thin green and reddish purple argillaceous sandstones of the Mistaken Point Formation pass upward into thin alternating units of light to dull grey graded argillaceous sandstone and dark grey to black parallel-laminated siltstone and shale. Along the river bed the sandstones have high relief and weather buff. North of Michener Avenue (near Drill Hole F), the Trepassey Formation grades upward into black shales of the Fermeuse Formation, with 10 to 30 cm thick shale units containing small scale slump folds of thin beds of disrupted sandstone.

Small outcrops of the Trepassey Formation occur along the western end of the Ruby Line and on the Harbour Arterial road near the Newtown overpass. Trepassey Formation subcrop and till occur north of Trepassey Place (southeast Canada Drive) and in the Barachois Street - Village Mall area.

Fermeuse Formation

Grey to black shales, minor buff sandstones and slumped beds of sandstones comprise the middle unit **(Fermeuse Formation)** of the St. John's Group. The Fermeuse Formation is the dominant lithology of the St. John's Group throughout the Avalon Peninsula and forms a large part of the Waterford River basin.

The formation is about 1400 m thick in southern Avalon Peninsula and can be traced northward to St. John's and Middle Cove (Figure 3). It is about 650 to 700 m thick in the map area and lies conformably above the Trepassey Formation with gradational contact. The lower half of the Fermeuse Formation has dark grey to black shales that commonly display large tight to isoclinal slump folds of shale and sandstone. These 1 to 5 m stratigraphically thick disrupted units are conformably overlain by black shale, suggesting that the slump folds were formed by gravitational slumping of sediment on a sloping paleosurface during normal pelagic sedimentation. The upper half of the formation consists of black shale with widely spaced (5 to 10 cm) laminae of buff weathering siltstone and very fine grained sandstone.

The mineralogical composition of the black shale consists of sericite, albite, quartz, and clay minerals, each forming 20 to 25 percent of the rock, with trace amounts of calcite, dolomite, pyrite, magnetite and apatite.

The shales contain some Vendian microfossils, including Bavlinella (Hoffman et al., 1979), but most microbiota recovered are either poorly preserved or include compressions of simple, allogenic spheroidal and filamentous forms with long stratigraphic range.

Problematical circular to oval markings from 1 to 5 cm in diameter occur at the top of the formation (Figure 3); they were interpreted by early workers as the trace fossil Aspidella terranovica, Billings, 1872. Good examples of these markings occur along the Old Petty Harbour Road north of Dunsmore Lane; some of the larger varieties may be medusoid impressions.

Renews Head Formation

The upper unit of the St. John's Group (**Renews Head Formation**) consists of alternating laminae and very thin beds of rusty weathering siltstone and lenticular-bedded sandstone set in dark shale. The Renews Head Formation represents a shoaling of the marine basin (Figure 5).

The formation is about 300 m thick in its type section at Renews Head, southern Avalon Peninsula. From there it increases to about 700 m at Bay Bulls and then gradually thins to about 250 m east of Flat Rock (Figure 3).

The Renews Head Formation is restricted to the eastern part of the Waterford River basin, where it forms the western limb of the Blackhead Syncline (Figure 4). The Renews Head Formation differs from the Fermeuse Formation by its greater sand content and distinctive small scale sedimentary structures. Lenticular-bedded sandstones show impoverished current ripples, pseudonodules and grading. Large scale channel-fill sandstones up to 10 m thick occur throughout the formation; a good example can be seen at the base of the formation near the Dunsmore Lane - Old Petty Harbour Road intersection.

Signal Hill Group

Alluvial plain conditions developed across the Avalon Zone by latest Vendian time in response to major uplift (north of the present Bonavista and Avalon Peninsulas) related to the Avalonian Orogeny. This period is represented by clastic rocks of the **Signal Hill Group** (Williams and King, 1979) on the Avalon Peninsula and by parts of the volcanic and clastic successions that comprise the **Musgravetown Group** and equivalents further west (Figure 1). The clastic successions of both groups contain grey and green tuffaceous siltstones and arkoses at the base, which are overlain by red and green arkoses and conglomerates. These contrast with the mainly dark shaly rocks of the St. John's Group.

The former Signal Hill Formation (Rose, 1952) with its type section at Signal Hill, corresponds with the original 'Signal Hill Sandstone' of Jukes (1843), the 'Signal Hill formation' of Murray and Howley (1881), and the 'Signal Hill Series' of Buddington (1919).

In the type area, the St. John's and Signal Hill rocks were defined as two of three formations of the Cabot Group (Rose, 1952). Because both formations are now elevated to group status, the name Cabot is dropped (Williams and King, 1979).

The Signal Hill Group is now known to include three distinct mappable units of formational status within the type area, which in ascending order are the **Gibbett Hill, Quidi Vidi,** and **Cuckold Formations.** All are confined to the South Side Hills and form the

steeply east dipping limb of the Blackhead Syncline. The Gibbett Hill and Quidi Vidi Formations form the eastern boundary of the Waterford River Basin.

Gibbett Hill Formation

Gibbett Hill, to the west of the Signal Hill Park Interpretation Centre, was named by the British in 1750 as victims of hangings were exhibited there on a gibbett. The hill is the type section of the **Gibbett Hill Formation** (King, 1972; Williams and King, 1979), a buff weathering tuffaceous sandstone which is greenish grey on fresh surface.

The Gibbett Hill Formation is about 110 m thick at Flat Rock, north of St. John's, and gradually increases southward to 750 m near Petty Harbout Long Pond, where it forms the steeply eastward dipping limb of the Blackhead Syncline (Figure 4). It reaches its maximum thickness of 1400 m near Bay Bulls and from there it gradually decreases to 760 m at Cape Ballard (Figure 3).

The base of the Gibbett Hill Formation in the map area is arbitrarily drawn where lenticular bedded sandstones and shales of the Renews Head Formation grade upwards into medium to thick beds of dominantly grey sandstone. This gradational zone is poorly exposed and is assumed to be less than 30 m thick. Steeply eastward dipping beds of medium to coarse grained, buff weathering grey sandstone dominate the upper half of the formation and are sharply overlain by red arkosic sandstones of the Quidi Vidi Formation.

The sandstone beds in the upper part of the Gibbett Hill Formation are up to 15 m thick and appear massive or homogeneous but careful examination reveals parallel laminations, amalgamation of multiple beds, and cross-stratification. Large and small scale tabular and trough crossbeds indicate paleoflow to the south and southwest. Mudcracks and channels at the top of the formation suggest the development of a subaerial paleoenvironment, probably as a southward prograding delta plain (Figure 5).

Thin sections of the medium to coarse grained sandstones from the top of the Gibbett Hill Formation near Petty Harbour Long Pond show that they are arkosic in composition. They are moderately well sorted with angular to subrounded clasts of quartz (20 to 35 percent), plagioclase feldspar (20 to 30 percent), orthoclase feldspar (<15 percent), rock fragments (15 to 25 percent), and groundmass (<15 percent). Rock fragments include rhyolite, tuff, altered basalt, granite, siltstone and quartzite. The groundmass consists of fine grains of quartz, feldspar and rock fragments with minor amounts of devitrified glass shards, sericite, chlorite, biotite, epidote, sphene, zircon, magnetite and calcite. Authigenic or secondary growths of quartz have substantially reduced the porosity and permeability of the rock.

Quidi Vidi Formation

The **Quidi Vidi Formation** (King, 1980) is composed of medium to thick beds of red and grey arkosic sandstone with interbeds of siltstone, mudstone, interformational breccia and red conglomerate. The base of the formation is sharp and erosional and the upper boundary with the overlying Cuckold conglomerate is gradational. The southward thickening formation (Figure 3) is well exposed between Flat Rock and Petty Harbour Long Pond in the southeastern part of the map area.

The dominantly fine to medium grained red arkosic sandstones comprising the 1100 m thick Quidi Vidi Formation are exposed on the eastern perimeter of the Waterford River basin where they dip steeply eastward and form the western limb of the Blackhead Syncline (Figure 4). Facies within the formation are characteristic of braided river deposits (King, 1972, 1980, 1982); paleocurrent studies of the trough crossbeds indicate southward flowing streams. Abundant mudcracks and mudflake breccias probably developed within playa or intermittent lakes.

Thin sections of medium grained sandstones from the base of the Quidi Vidi Formation at Petty Harbour Long Pond show that they are arkosic in composition. They are poorly to well sorted with angular to subrounded clasts of quartz (30 to 35 percent), plagioclase feldspar (20 to 25 percent), orthoclase feldspar (15 percent), rock fragments (15 to 25 percent) and groundmass (20 percent). The rock fragments are similar in composition to those in the Gibbett Hill Formation but are dominated by felsic volcanic rocks. Finely disseminated hematite surrounds the grains and gives the rock its red colour.

Cuckold and Blackhead Formations

The red arkosic sandstones of the Quidi Vidi Formation gradually pass upwards into the overlying red conglomerate and arkose of the **Cuckold Formation** (King, 1980). The conglomerates are well exposed 1 km east of the Waterford River basin boundary. They form part of the western limb of the Blackhead Syncline and reappear on the eastern limb at Cape Spear National Park, the most easterly place in North America (Figure 4). Within the trough of the Blackhead Syncline, there are red and grey sandstones of the **Blackhead Formation,** the highest stratigraphic unit within the St. John's region.

Facies developed in the Quidi Vidi, Cuckold and Blackhead Formations are characteristic of braided-river deposits (King, 1980). Paleocurrent studies of large scale trough crossbeds within the Cuckold and Blackhead Formations indicate southward flowing streams (Figures 4c and 5).

The Cuckold Formation to the east of the map area consists of three members of roughly equal thickness (Figure 3): the lower and upper members are conglomerate and the middle member consists of alternating medium to thick beds of arkose, pebble conglomerate and minor red mudstone.

About 80 percent of the pebbles within the Cuckold Formation are composed of felsic volcanic rocks with lesser amounts of granite, mafic volcanic rocks, sandstone, siltstone, chert and quartzite. The maximum diameter of clasts shows a gradual southward decrease in size (Figure 4). The upper member **(Cape Spear Member)** contains the largest clasts (Figure 4), including some of quartz mica schist which are exotic to the Avalon Peninsula.

The Cuckold conglomerates wedge out to the south by passing into a red sandy facies near Bay Bulls that resembles both the Quidi Vidi and Blackhead Formations. These combined units at Ferryland are termed the **Ferryland Head Formation** (Williams and King, 1979); the decrease in clast size, the relatively high silt content, and the presence of thixotropic deformation structure indicate a more distal alluvial-plain environment.

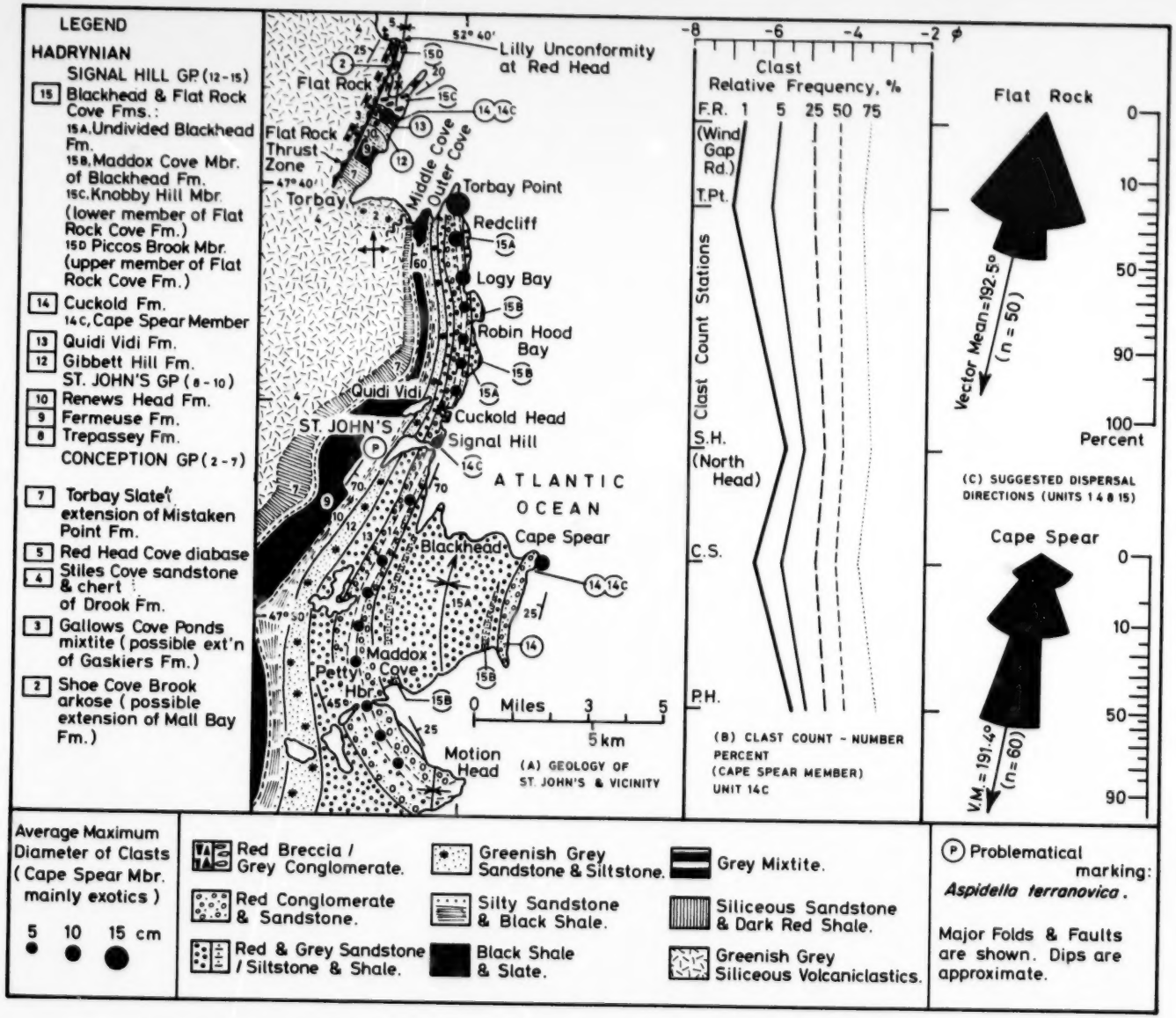
LEGEND
HADRYNIAN
SIGNAL HILL GP. (12-15)
15 Blackhead & Flat Rock Cove Fms.:
15A. Undivided Blackhead Fm.
15B. Maddox Cove Mbr. of Blackhead Fm.
15C. Knobby Hill Mbr. (lower member of Flat Rock Cove Fm.)
15D Piccos Brook Mbr. (upper member of Flat Rock Cove Fm.)
14 Cuckold Fm.
14C. Cape Spear Member
13 Quidi Vidi Fm.
12 Gibbett Hill Fm.
ST. JOHN'S GP (8-10)
10 Renews Head Fm.
9 Fermeuse Fm.
8 Trepassey Fm.
CONCEPTION GP (2-7)
7 Torbay Slate (extension of Mistaken Point Fm.)
5 Red Head Cove diabase
4 Stiles Cove sandstone & chert of Drook Fm.
3 Gallows Cove Ponds mixtite (possible ext'n of Gaskiers Fm.)
2 Shoe Cove Brook arkose (possible extension of Mall Bay Fm.)
52° 40'
Lilly Unconformity at Red Head
Flat Rock
Flat Rock Thrust Zone
47° 40'
Torbay
Middle Cove
Outer Cove
Torbay Point
Redcliff
Logy Bay
Robin Hood Bay
Quidi Vidi
Cuckold Head
ST. JOHN'S
Signal Hill
ATLANTIC OCEAN
Cape Spear
Blackhead
47° 30'
Maddox Cove
Petty Hbr.
45°
Motion Head
0 Miles 3 5
5 km
(A) GEOLOGY OF ST. JOHN'S & VICINITY
-8 -6 -4 -2 ϕ
Clast Relative Frequency, %
F.R. 1 5 25 50 75
(Wind Gap Rd.)
T.Pt.
S.H. (North Head)
C.S.
P.H.
Clast Count Stations
(B) CLAST COUNT - NUMBER PERCENT (CAPE SPEAR MEMBER) UNIT 14C
Flat Rock
Vector Mean=192.5°
(n = 50)
0 10 50 90 100 Percent
(C) SUGGESTED DISPERSAL DIRECTIONS (UNITS 1 4 8 15)
Cape Spear
V.M. = 191.4°
(n = 60)
0 10 50 90
Average Maximum Diameter of Clasts (Cape Spear Mbr. mainly exotics)
5 10 15 cm
Red Breccia / Grey Conglomerate.
Red Conglomerate & Sandstone.
Red & Grey Sandstone / Siltstone & Shale.
Greenish Grey Sandstone & Siltstone.
Silty Sandstone & Black Shale.
Black Shale & Slate.
Grey Mixtite.
Siliceous Sandstone & Dark Red Shale.
Greenish Grey Siliceous Volcaniclastics.
P Problematical marking: Aspidella terranovica.
Major Folds & Faults are shown. Dips are approximate.

Figure 4: Geology of St. John's and vicinity (modified after King, 1982).

STRUCTURAL GEOLOGY

Tectonic Setting

Two periods of deformation have been identified in eastern Avalon Peninsula: (1) an enigmatic Late Riphean to Vendian (Cadomian or Pan-African) Orogenic episode, named the "Avalonian" by Rodgers and first described as the "Avalonian Orogeny" by Lilly (Hughes, 1970); (2) a major Siluro-Devonian (circa 395 Ma) disturbance - the "Acadian Orogeny".

The effects of the late Precambrian Avalonian Orogeny are enigmatic. Pre-Tommotian unconformities in widespread localities throughout the Avalon Peninsula provide evidence of mainly Vendian folding, block-faulting, granitoid emplacement (620 Ma Holyrood Plutonic Suite) and general crustal instability (e.g. McCartney, 1967; Anderson et al., 1975; King, 1980, 1982). The present concentric arrangement of late Precambrian sedimentary rocks around a volcanic core in the eastern Avalon (Figures 1 and 2) appears to be the result of Precambrian structural doming, as Lower Cambrian strata overstep the Conception Group to lie directly upon the Holyrood granite and Harbour Main volcanics at Conception Bay (McCartney, 1967).

The effects of Acadian deformation and metamorphism in the Avalon Zone of Newfoundland are dominant but variable, reflecting the inhomogeneity of the Acadian event. Metamorphism in eastern Avalon Peninsula occurred under prehnite-pumpellyite facies conditions (Papezik, 1974).

In the following account, major and minor tectonic elements within the map area are described. Their hydraulic implications with respect to groundwater flow are briefly discussed.

Major Tectonic Elements

The Precambrian rocks of the map area provide evidence of two phases of deformation. The first phase is observable in the Mount Pearl - Kenmount Hill area and is assumed to relate to the Avalonian Orogeny. It is characterized by tight to isoclinal folds and associated faults that have been refolded about north-northwest to northeast trending axes. Examples of early folds are the Wishingwell Road Anticline and the Georges Pond Syncline within the Kenmount Hill Anticlinorium.

The second phase of deformation is assumed to relate to the Acadian Orogeny. Continued compression produced major open folds with steep axial surfaces and coplanar cleavage. Examples are the gently northward plunging Paddy's Pond and Cochrane Pond Anticlines and the Glendale and Blackhead Synclines. These plunging structures are important conduits for groundwater movement and the synclines are potential aquifers.

The Kenmount Hill Anticlinorium provides evidence of multiple deformations. It is a complex horst-like block of tightly folded Drook strata; both early folds and associated faults within the block have been refolded or warped about a major northerly trending axis. It is possible that the younger, open folds resulted from warping and southward decollement detachment of the block above a resistant basal unit, as may be provided by the Harbour Main volcanic rocks. Black shales of the St. John's Group exposed along Waterford River between Donovans and Branscombes Pond are separated from the block by the Donovans-Blackmarsh Fault; both tight folds in the shales and the Donovans Fault are warped around the

southern end of the Kenmount Hill Anticlinorium. A steeply dipping, north-northwest trending, slaty cleavage is well developed in the Fermeuse Formation in the Newtown area and is possibly a product of the younger folding phase.

The South Brook Anticlinorium extends from downtown St. John's along part of South Brook to the Goulds. It consists of a north-northeast trending, 500 to 1000 m wide zone of tightly folded, faulted and disrupted strata of the Fermeuse Formation. Spectacular minor folds are exhibited along South Brook, especially where the Harbour Arterial Road crosses the South Brook River. This zone resulted from intense compression of incompetent shales between relatively competent sandstones within the Kenmount Hill Anticlinorium and the Blackhead Syncline.

The Donovans Fault trends parallel to the Waterford River in the Donovans-Mount Pearl area and is interpreted to splay into two or more faults northeast of Mount Pearl. This fault is poorly exposed in the map area, except for local zones of intense rock fracturing, brecciation and massive quartz veining north of Branscombes Pond; its trace, however, at Donovans and throughout most of its length is marked by structural discontinuity, with its southern side downthrown.

The northeast trending Kenmount Road Fault is a narrow (<100 m wide) fault zone that defines the northern margin of the Kenmount Hill Anticlinorium. Closely spaced and steeply northwest dipping faults are exposed at several localities along is length (e.g. behind radio station VOCM). It is interpreted as a pivotal normal fault with the north side downthrown, and displacement increasing in a northeast direction. Slickensides and rock plucking along the fault surface indicate normal or down-dip movement.

The headwaters of South Brook follow a low generally eastward trending valley, which crosses the Cochrane Pond Anticline. Although there is little rock exposure, the axis of the Cochrane Pond Anticline appears on aerial photographs to be offset, suggesting the presence of a minor fault. This assumed strike-slip rupture is referred to as the Newtown Fault. It extends almost to the Trans Canada Highway, where it appears to originate as a bedding plane fault; to the east of the Harbour Arterial Road/Ruby Line intersection, it passes into the South Brook Anticlinorium.

Minor Tectonic Elements

Numerous joint sets and fracture zones are evident in virtually all rock units present in the map area. Joint systems are especially well developed in thick bedded sandstones and conglomerates of the Signal Hill Group.

Rhombohedral joints are characteristic of the Signal Hill Group and probably developed perpendicular to the stratification during early stages of folding. A fourth penetrative joint set (azimuth 105°; dip 35°N) in the Gibbett Hill Formation near Petty Harbour Long Pond is filled with white quartz and minor pale green prehnite, and traces of calcite, pyrite and pyrolusite. This set can be traced from Petty Harbour to Torbay Point; quartz veining substantially reduces groundwater movement.

Open fracture zones (i.e. closely spaced, highly interconnected discrete fractures) are characteristic of the siliceous Drook Formation. Iron (derived from weathered pyrite, hematite and magnetite) and manganese (pyrolusite)

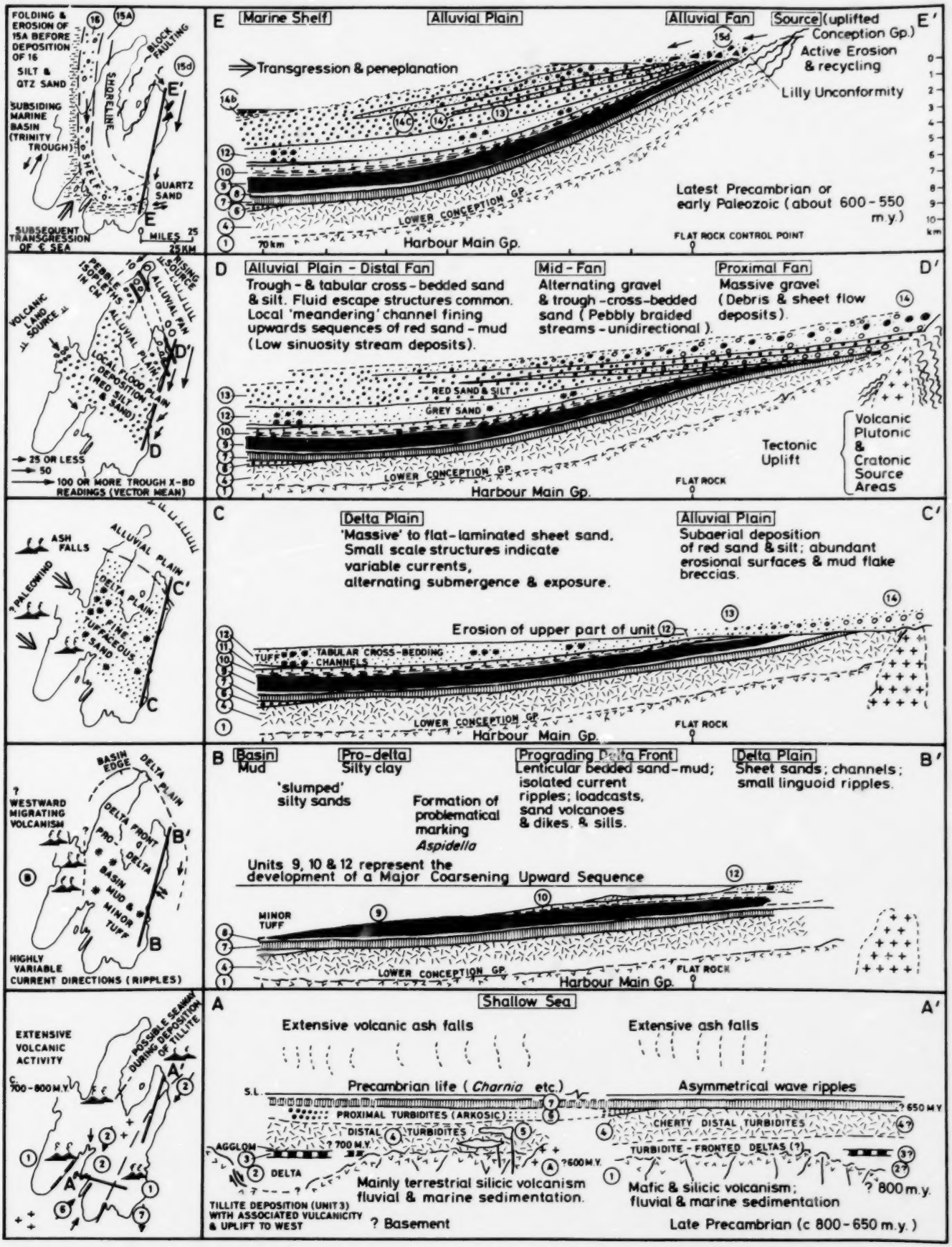

Figure 5: Late Precambrian and Early Paleozoic development of the Avalon Peninsula. Legend as for Figure 2. (King, 1982).

are common stains along fracture surfaces and indicate that fracture zones and, to a lesser extent, bedding surfaces are the primary conduits for groundwater movement in these otherwise well-cemented, low matrix porosity rocks.

Steeply dipping fractures and slaty cleavage are characteristic of the more argillaceous bedrock units such as the Mistaken Point, Trepassey, Fermeuse and Renews Head Formations. The north-northwest trending slaty cleavage in the Fermeuse Formation in the Newtown - Mount Pearl area provides a conduit for groundwater movement and the migration of iron and manganese.

PALEOGEOGRAPHIC EVOLUTION

Schematic diagrams of the proposed evolution of the Avalon Peninsula, shown in Figure 5, are based on regional studies by King (1980) and are applicable to the Precambrian rock units in the map area. They reflect a long history of volcanic activity, uplift and subsidence.

Facies relationships indicate an early history of widespread marine turbidite and pelagic sedimentation (Conception Group) around an active volcanic archipelago (Harbour Main Group). The St. John's Group black shales record a shoaling of the marine basin, and then southward prograding deposition of deltaic sands of the Gibbett Hill Formation. Local tuff beds in the Drook and Mistaken Point Formations diminish upward in the St. John's Group and record waning volcanic activity. Tuff beds in the Gibbett Hill and overlying formations of the Signal Hill Group record intermittent deposition of volcanic ash. The presence of tuff and ash beds in the Signal Hill Group indicates contemporaneous sporadic volcanic activity, possibly originating in the Bull Arm region to the west of the Avalon Peninsula. It is noteworthy that mafic and felsic volcanic rocks which formed mainly in a subaerial environment between circa 650 and 570 Ma extend from the Bull Arm region throughout the entire eastern margin of the Appalachians. This period was a time of Precambrian Avalonian movements. In eastern Newfoundland, a rising mountain front on the northern periphery of the present Avalon Peninsula gave rise to alluvial plain conditions, now represented by red sandstone (Quidi Vidi Formation), conglomerates (Cuckold Formation) and variegated sandstones and mudstones (Blackhead Formation), all of which are a molasse-like sequence resulting from tectonic upheaval.

Rock fragments and constituent detrital minerals indicate that the Signal Hill Group was derived largely from a source area of Harbour Main, Conception, and Holyrood rocks. However, the Gibbett Hill Formation also contains small amounts of detrital garnet and muscovite (Papezik, 1973); this, together with a northesterly provenance of the Signal Hill Group sediments, may indicate the presence of basement rocks on the continental shelf to the northeast of the Avalon Peninsula.

The tectonic significance of the Avalon Zone and its extensions in any plate tectonic model for the Caledonian-Appalachian Orogen of the North Atlantic region is at present poorly understood. The overall similarity in age, lithology, faunal assemblages and tectonic history between the Avalon Zone of Newfoundland and Pan-African belts of northwest Africa (Figure 6) implies that they evolved in similar tectonic environments (King and O'Brien, in press). Some authors (e.g. O'Brien et al., 1983) have suggested that the Avalon Zone of eastern Newfound-

land is part of a larger Pan-African belt that separated and was incorporated as an ancient fragment of northwest Africa into the remainder of the Appalachian Orogen during or after closure of the Paleozoic Iapetus Ocean. The Avalon Zone probably represents a wide distentional belt (Strong, 1979) and partly marine basin and range domain that predated the opening of the Paleozoic Iapetus Ocean, i.e. an "Avalonian cycle" representing the final stages of a Precambrian orogenic cycle that is related only spatially to Paleozoic rocks of the Appalachian Orogen (Williams and King, 1979).

Geological events in the Avalon Peninsula are recorded in rocks up to about 200 million years ago. Extensive offshore oil exploration and marine geological studies to the east and southeast of the Avalon Peninsula will no doubt complete the gap in knowledge of the geological history of the region up to the time of the last ice age.

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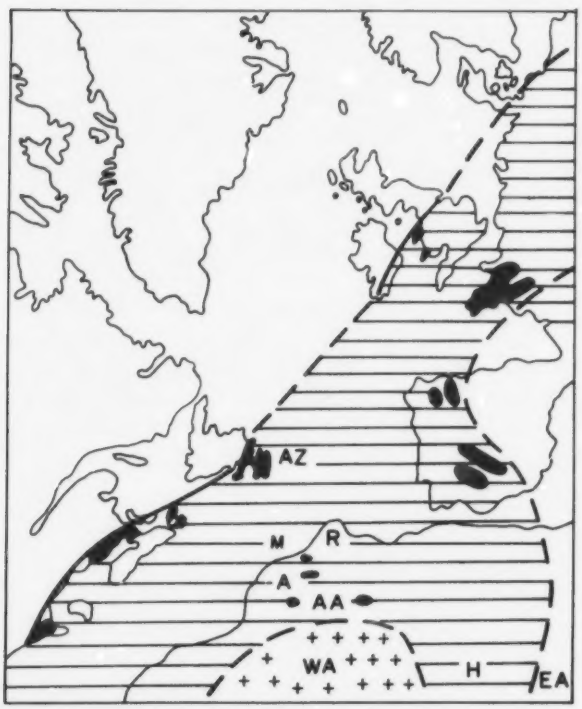

Figure 6: Distribution of Avalonian - Cadomian - Pan-African terranes in the North Atlantic borderlands, plotted on the Pre-Mesozoic reconstruction of LePichen et al., 1977. AZ = Avalon Zone, R = Rif, M = Meseta, A = High Atlas, AA = Anti-Atlas, WA = West African Craton, H = Hoggar, EA = East African Craton (King and O'Brien, in press).

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